This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

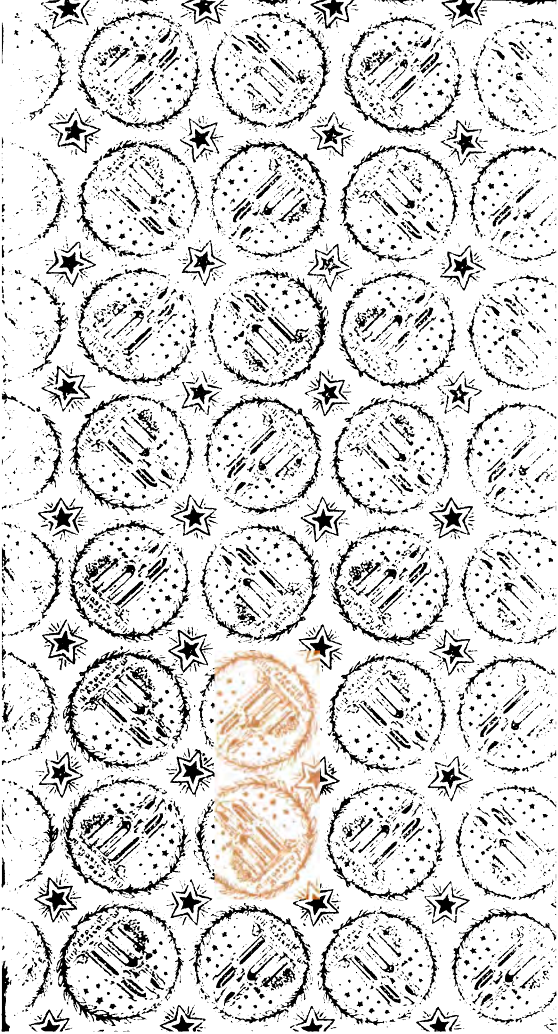
+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

F82
F

Library
of the
University of Wisconsin



Fuels, Evaporation and Combustion.

Translated and Reduced to American Standards

BY

GEORGE L. FOWLER,

EDITOR "POWER,"

FROM THE FRENCH OF

J. BUCHETTI.

1887.
AMERICAN RAILWAY PUBLISHING CO.,
118 LIBERTY STREET, NEW YORK.

Am. Ry. Pub. Co. Print.

THN
151667 .F82
APR 4 1911 F
6952005

PREFACE.

This little book is offered to those who are interested in the care or ownership of steam boilers, and to whom the question of the consumption of fuel is of vital importance. Too little is known by the men in charge of the steam plant regarding the constituent elements of the fuels that they are using, and the meaning of the dense volumes of smoke that issue from almost every chimney in the country. Smoke is nothing but smoke to very many and seems to be considered an indispensable accompaniment to the burning of fuels of every kind.

An attempt has been made to simplify the grades into which ordinary fuel has been divided and to show how it can best be employed in the production of steam. There is also added a description of a means of testing the products of combustion and thus learning whether the best results have been obtained.

While the book is only one of a series that will be issued on the general subject of the testing of the steam engine and the means employed to determine its efficiency, it will be found to be complete in itself and to contain, it is believed, much data that is new and valuable to the man in charge of the steam plant. G. L. F.

New York, Dec. 6, 1886.

FUELS, EVAPORATION AND COMBUSTION.

I. FUELS.—CALORIFIC POWER.

The sun, which is the source of all vegetation, has at some time had shut up within itself all that heat which is now made available in the several fuels.

All those bodies are called fuels which are capable of combining with the oxygen of the air. Such a combination is combustion, and restores the heat and light that had originally been taken from the sun.

Commercial fuels are supposed to contain when dry: 1. A certain amount of oxygen and hydrogen combined in the proportion of eight to one, forming the constituents of water and furnishing no heat. 2. A certain amount of inert substances which also give out no heat, as azote, the mineral matters composing the cinders, and frequently iron pyrites or sulphate of iron, which may be disregarded because of the feeble calorific power of sulphur. 3. Finally, free carbon and hydrogen, which are the elements of combustion in the production of heat. We will now review this combustion.

In judging of the quality of a fuel, we must look to its resulting heating power, its density, its cohesion, its behavior upon the grate, the readiness with which it burns, and, finally, the nature of the resultant cinders.

Those which are argiloferous or of a clayey nature, containing iron, produce by their fusion a kind of iron dross which clogs and burns the grates, while those which are of an earthy nature fall through without obstructing the passage of the air. The *calorific or heating power* (P) of a fuel is then the number of calorics or heat units which a pound will disengage in the course of its combustion. According to Dulong it is equal to the sum of the calorific powers of its elements, namely, free carbon and hydrogen.

According to Fabre and Silberman the calorific power of carbon, which is represented by C, is 14,580; that of hydrogen, H, is 62,150. (By this the reader should bear in mind that this calorific power represents the number of heat units in one pound of carbon or hydrogen. A *heat unit* is the amount of heat required to elevate the temperature of one pound of distilled water one degree Fahr. from 39° to 40°.

The water is taken at this point because it has there its greatest density. So that for the case in hand we learn that one pound of carbon, when completely consumed, would raise 14,580 pounds of water one degree Fahr.—*Trans.*) In analyses of fuels oxygen is frequently confounded with azote, the latter being of little importance. Oxygen (O) being combined with hydrogen (H) in the proportion of eight to one to form water, the proportion of the free hydrogen in the fuel would be $H - (O \div 8)$, or the total weight of the hydrogen in the fuel less one-eighth the weight of the oxygen, this one-eighth being united with the oxygen.

Dulong's formula for the pure fuel is $P = C \times 14{,}850 + (H - (O \div 8)$ or) $62{,}150$

(The meaning of this is that C, H and O represent the percentage of carbon, hydrogen and oxygen in the fuel. An example will be given later.—*Trans.*)

This law is not exactly correct for fuels possessing a high percentage of hydrogen, but such should be tested by means of a calorimeter. If a is put equal to the percentage of water, and b to that of cinders, the true calorific power may be expressed as: $P' = P\ (1\text{-}a\text{-}b)$. That is, supposing that: 1. The steam formed during combustion is condensed and then cooled to 32° Fahr., so that it gives up all the heat absorbed in its evaporation. 2. That all the other residues are also cooled to 32°. But it must not be understood that this state of affairs obtains with boilers; the steam passes out into the chimney and carries with it 1146.6 units of heat for each pound of steam when the temperature is considered to be 212° Fahr., to which must be added the heat corresponding to the excess of 212° existing in the temperature t of the gases in the chimney or $(t - 212.)$

(For example, suppose a pound of steam is carried off among the gases having a temperature of 240°, then 1146.6 units are lost for the first 212° and $.3 \times (240 - 212) = 3 \times 28 = 8.4$ units additional or $1146.6 + 8.4 = 1155$ in all, the .3 being a fixed coefficient.—*Trans.*)

If h is the weight of hydrogen contained in one pound of fuel, its combustion yields $9\ h$ of water for $8\ h$ (of oxygen) is united to h, and the total amount of water evaporated is a plus $9\ h$, or the original water contained in the fuel and that formed by he combustion of the hydrogen.

It becomes necessary, then, to deduct

from the true calorific power (P′) of the fuel the heat which remains in the cinders and ashes; but this loss as well as that due to the temperature (*t*) of the escaping gases, is among the other causes of loss in the fire-boxes, and can be determined, as we shall see, by multiplying the absolute calorific power by a coefficient upon the basis of a reduction to a temperature of 32° of the condensed water. We take then:

The true calorific power $P' =$ theoretical calorific power $P\ (1 - a - b) - 1146.6\ (a$ plus $9\ h.)$

Commercial fuels may be divided into five classes:

Wood, charcoal, barks.
Peat, peat charcoal.
Lignite.
Bituminous coal, coke.
Anthracite coal.

To these solid fuels we may add: Gas, oil, tar, petroleum.

WOOD.

Woods may be distinguished as hard and soft, or green and dry.

According to Brisson, the average specific gravities of different woods may be written as follows:

Heart of dry oak	1.17
Beech and ash	.84 to .85
Alder " apple	.79 " .80
Maple " cherry	.75
Elm " walnut	.67
Pear	.66
Willow	.58
Fir (male)	.55
" (female)	.49
Poplar	.38
Cork	.24

Wood always contains more or less of water, and can only be used after having been partially dried either in the air or in a dry house at a high temperature. Wood should be cut during the winter. It then contains from 40 to 45 per cent. of water; after 6 months it will have 26 per cent.; after a year 20 per cent., and after 18 months about 17 per cent.; after which time wood that is merely exposed to the air will lose no more water; but when wood has been previously dried and is afterwards exposed to the air it will gradually re-absorb from 14 to 16 per cent. of water.

Wood that has been dried at a temperature of 285°, contains 50 per cent. carbon; 1 per cent. free hydrogen; 46 per cent. of oxygen and hydrogen in the proportions necessary to form water ; 1 per cent. azote and 2 per cent. cinders.

According to the law of Dulong we have: $P = .5 \times 14{,}580 \times .01 + 62{,}150 = 7{,}911.5$.

This remodeled according to our directions gives $P' = 7{,}911.5 - 1{,}009.\ (.46 + .09) = 7{,}356.5$ caloric units. (This $1{,}009 = 1{,}146.6 \times .88$. The .88 being 100 less the percentage of ashes and hyrogen. 1,146.6 is the number of calorics required to evaporate one pound of water from 32° Fahr. — *Trans.*)

The following table contains the weight and calorific power of one cubic foot of wood heated to 285°, according to Chevandier.

That of one pound of wood varies from 7,660 units of heat to 7,920; average about 7,911, as given above.

Hard wood burns upon the surface, furnishing abundant carbon, while soft wood cracks open under the influence of the fire and burns rapidly down to the center, sending forth flames until the end of the combustion.

The more wood is cut up the more rapid is the combustion, and the greater the useful effect, because the air is more effectually utilized; but this cutting up is a source of expense.

	Kind of Wood.	Wt. in lbs per c. ft.*	Carbon...	Free Hydrogen.	Heat Units	
					per cub. ft.	relative
From trunks.	Oak from old trunks	23.65	11.70	.1626	191,450	1.
	Beech................	23.65	11.46	.1643	190,313	0.994
	Elm—(yoke).........	23.03	11.13	.1355	181,680	0.95
	Oak—(small trunks).	22.28	11.08	.1538	180,863	0.945
	Birch................	21.05	10.71	.2273	179,806	0.939
	Alder................	18.24	9.26	.1855	155,590	0.812
	Fir..................	17.25	8.78	.1626	145,961	0.762
	Pine.................	15.44	8.19	.1483	135,236	0.706
Fr. branches.	Beech................	18.92	9.26	.1313	152,246	0.795
	Fir........	17.86	8.09	·1681	150,016	0.79
	Pine......	17.49	8.89	.1626	148,425	0.779
	Elm—(yoke)....	18.55	8.95	.1146	146,240	0.764
	Birch..	17.74	8 47	.1806	143,379	0.749
	Oak—(both kinds)...	17.25	8.51	.1184	139,533	0.728

Wood charcoal is obtained by carbonization in furnaces in the forests. Calcination begins at 302° Fahr., and the product varies with the temperature. When subjected to

From 302° to 518°, the production = 30 to 37 per cent. in the form of firebrands.

From 536° to 626° production = 32 to 36 per cent. as brown coal.

From 644° to 752°, production = 18 to 31 per cent. as black coal.

From 752° to 2,750, production = 17 to 18 per cent. as hard and black coal.

The production in weight, which is really the only thing that should be considered, varies from 18 to 20 per cent. of the original weight.

The weight per cubic foot varies according to the nature of the case.

	At the center.
For oak and beech	14.94 to 15.55 lbs
" birch	13. 7 " 14.39 "
" pine	11.45 " 13.07 "

According to Ebelmen the average composition of charcoal that has been deprived of water is :

Carbon	875 parts
Hydrogen	030 "
Oxygen and agate	075 "
Ashes	020 "
	1000 "

The free hydrogen amounts to about 2 per cent., and the heat units are $P = .875 \times 14{,}580 \times .02 \times 62{,}150 = 14{,}000.5$, which, for a pure fuel, would be :

$$\frac{14{,}000.5}{.98} = 14{,}286.22$$

For a charcoal containing .06 of water and .04 of ashes, we should have .09 of carbon anp the formula would become :

$P' = 14{,}286.21 \times .9 - 1{,}009\ (.06 + .9)\ .02 = 12{,}888.95.$

The relative values of the different charcoals are in proportion to the weights of the same volumes or their specific gravities.

Bark, Tanbark and Sawdust.—These fuels are very finely divided and generally damp. Theoretically they have the same heating capacity as the wood from which they are obtained. Tanbark, after its passage from the press to the cylinder, contains about 4.8 per cent of water, 8 to 12 per cent of ashes, and weighs 20¼ lbs. per cubic foot. Its true heating capacity, deduced from dry wood with 2 per cent of ashes, will be

$P' = 7.911.5 \quad (1 - .48 - .1) - 1.009 \times .48 = 2,838.51.$

Admitting that 40 per cent can be utilized, we would have $2,838.51 \times .50 = 1,135.4$, and $1,354 \div 1,009$, the total units of heat absorbed $= 1.12$ lbs of steam per lb of fuel.

Now actual tests have given 0.82 lbs. of steam per lb. of tanbark, and 0.90 lbs. per lb of sawdust.

These fuels burn better if mixed with bituminous coal. Their poor utilization results from a part of the fuel being carried off into the flues.

PEAT.

Peat (mossy, leafy or from embers) results from actual vegetable decomposition. This is very apparent in the upper layers, while for the lower layers which are denser and blacker, these vegetable formations are no longer distinguishable.

Peats dried in the open air contain, according to the localities, from 20 to 30 per cent. of water, and from 10 to 25 per cent. of ashes. The weight of a cubic foot weighs from 14 lbs. to 19 lbs. The fuel is light, cumbrous and spongy; it burns poorly with a smoke of a strong and disagreeable odor. After grinding and washing it is pressed into briquettes.

Peat is improved by drying up to a temperature of 212°, (or below that which causes its decomposition) but it is necessary to use it where it is dried, if not it will re-absorb the dampness.

The analyses of Regnault and Marsilly show that dry and pure peat contains on an average:

Carbon	.57
Hydrogen	.06
Oxygen and azote	.37
	1.00

The free hydrogen gives $.06 - \frac{.37}{8} = .0137$

The heat units are theoretically P =

$0.57 \times 14580. + .0137 \times 62150. = 9126.05.$

And the real capacity $P' = 9126.05 - 1{,}009. (9 \times 0.06) = 8{,}582.19.$

For a peat containing 8 per cent of ashes and 25 per cent of water the capacity would be, $P' = 8{,}582.19 \times .67 - 1{,}009 \times .25 = 5497.81$ (.67 = 1.00 — .08 (% of ashes) — 25 (% of water) *Trans.*)

Peat charcoal is obtained by carbonization of the peat in furnaces, in mason-work pits or kilns, or in sheet iron crucibles.

The product contains from 40 to 45 per cent. of carbon, and from 15 to 20 per cent. of ashes.

The gas resulting from the combustion of this charcoal preserves the strong and disagreeable odors of the peat.

The Essone charcoals with 18 per cent of ashes have a calorific power of $.82 \times 14{,}580 = 12{,}155.6$ for the fuel itself when deprived of water.

FOSSILIZED FUELS.—LIGNITES.

These fuels mark a transition state between the peats and the coals. They are sometimes brown with a ligneous texture, or of an earthy appearance, sometimes black with a ligneous texture, orhomogeneous, giving a resinous fracture. These last, jet for instance, are analogous to coal.

Regnault distinguishes *imperfect lignites* or fossilized wood in the process of transformation into lignite; *perfect lignites*; and the *lignites* or *bituminous woods* in process of transformation into bituminous coals. They are characterized by the proportions of the oxygen to hydrogen, and the fixed carbon or coke which they contain.

The calorific power (P) of the pure fuel has deen directly determined by Messrs. Scheurer-Kestner and Meunier.

Fuel.	Coke per ct.	$\frac{O}{H}$	H	P	P_1
Imperfect lignite.......	75	5 to 6	4	9526	9100
Perfect "	65 to 70	5	4	12780	10010
Bituminous "	35 to 40	1 to 2	6	14040	11420

With .08 of water and .10 cinders, for the three varieties we obtain the true caloric value P_1.

For instance for perfect lignite we have $P_1 = 12{,}780 \times .82 - 1009\ (.08 + 9 \times .04) = 12{,}414.$

COALS.

Their color is black, their appearance schistous or compact. They comprise a great number of varieties. Regnault and Gruner divide them into five classes.

Coal, dry, producing a long flame.

" oily, producing a long flame (suitable for making gas.)

" oily (blacksmith coal.)

" oily, producing a short flame (suitable for coking.

Coal, hard or anthracite, or dry, with a short flame.

Dry coals, producing a long flame:—

Sandkohle (German), *Splint coal* (English). These give 60 per cent. of a coke slightly calcined, in pieces that possess little adherence; the flame is long but of short duration. These coals are used upon a grate and under boilers but have lower heating properties than those that follow. A cubic foot weighs 57 lbs. They are rarely found in France; those that most nearly approach them are those of Saint-Eloi and those of the upper beds of Blanzy and Montceau.

Oily coals with a long flame. Cherry coal (English). These agglutinate in the fire without caking. They are fine coals for the grate and for gas making. The *Flenu* of Mons and the cannel coal of England are the finest samples of this kind of coal They are more abundant in France than those that have been just mentioned and form the upper beds of the Pas-de-Calais, of the Loire, of Commentry and Blanzy.

Oily blacksmith coals. Coking coal, (English), *Backkohle,* (German). These have an oily appearance and are of a beautiful black; they are not very hard and have a structure that is more or less leafy or laminated; in the fire, they yield to a more or less putty-like fusion and produce a light, swoollen coke that is of little use in metallurgical processes. There are a few grades that give a good coke. Upon the grate they cake, intercept the air and burn the bars, but give a great deal of heat. They abound in France in the basin of Saint-Etienne, of the North and of the Pas-de-Calais. A cubic foot weighs from 57 to 65 lbs.

Oily coals producing a short flame.— These are less liable to cake than those that have just been mentioned, give a good coke and are preferably used in metallurgical processes. In Belgium they are called *lasting* because they last well in the fire; in reality they are friable. They are found in France at Creuzot, at Saint-Etienne, Brassac, Huy, in Gard and the North.

Delautel made some tests of this kind of coal at Brest.

The calorific power of the English coal from Cardiff being considered as 1, he found for the

Oily coal of Anzin	1.05 to 1.01
Coals from Roche-la-Moliere	.95 to .94
Coals, (ordinary), from the Loire	.90
" from Newcastle	.84
" " Blanzy (Montceau)	.78
" (dry) with long flame "	.74

Hard or anthracite coals with a short flame.—These are black, striated, offer a dull fracture, have slight cohesive qualities, burn with some difficulty, produce no smoke and often crackle while burning. Their coke is in the form of a powder They are rare in France, and are not burned upon the grate there. A cubic foot weighs 69 lbs.

Average weight of a few coals:

Mines of Labarth	56 lbs.
" Auvergne, Blanzy	55 lbs.
" Combelle	54 lbs
" Lataupe	53½ lbs.
" Saint-Etienne	53 lbs.
" Decize	52 lbs.
" Mons	80 lbs.
" Creuzot	49 lbs.

The *calorific power* of coal has been measured by several experimenters. In table A we give the averages: 1st, of the elementary composition: 2nd, of the yield of coke, which characterizes the five types of coal that are supposed to be pure; 3rd, of the theoretical calorific power (P); and 4th, of the amount of water that can be evaporated at 248° taken at 32° Fahr.

For coal containing 2° of water, 10° of cinders, the proportion of hydrogen will be reduced to $.88 \times .05$ and

$$P' = 15{,}570 \times .88 - 1{,}009\,(.02 + 9 \times .044) = 13{,}298.$$

Table A.—*Giving the average of five kinds of coal.*

Kinds of Coal	Composition. Per cent.			Ratio. O/H	Av. caloric po 0 pure coal..	Wtr. evap. from 32°...	Coke.	
	C	H	O				per ct..	Nature.
Dry, with long flame.	75 to 80	5.5 to 4.5	19.5 to 15.5	4 - 3	14400 to 15300	6.7 to 7.5	50 to 60	Brittle and powdery.
Oily, with long flame	80 to 85	5.8 to 5	14.2 to 10	3 - 2	15300 to 15530	7.6 to 8.3	60 to 6	Heavy and porous.
Oily, merchant	84 to 89	5 to 5.5	11 to 5.5	2 - 1	15840 to 16740	8.4 to 9.2	6 to 74	Heavy and swollen.
Oily, with short flame	88 to 91	5.5 to 4.5	6.5 to 4.5	1	16740 to 17280	9.2 to 10	74 to 82	Heavy and compact.
Dry or anthracite	90 to 93	4.5 to 4	5.5 to 3	1	15840 to 17400	9 to 9.5	82 to 90	Brittle and powdery.

It is in this way that we have calculated the calorific power (P′) of table (C).

We learn the value of a coal by making a direct analysis. After a drying which gives the hydrometric proportion of water, we distill the remainder in a close vessel in order to determine the nature and quantity of the coke; then by burning the residue left from the distillation the proportion of cinders is determined.

This drying is carried up to about 230 degrees by putting from 60 or 75 grains of the material in a test tube. The incineration is effected upon about 50 grains of material, confined in porcelain capsules placed in a muffle or oven that has previously been heated to a white heat in order to avoid the formation of coke, which hinders the operation.

Several capsules are operated upon at the same time, an average taken of the result. The incineration occupies two hours with coal and four with coke. The direct evaporative tests made by Messrs. Scheurer-Kestner and Brix, given in resume in the following table, agree with the data of the preceding. In reckoning 1146.6 calf orics per pound of water at 212° Fahr., we have deduced the co-efficient for each type of coal (K) that may be considered pure. We can then adopt .6 as the average.

TABLE B.—*Evaporative Results.*

Kind of Coal.	Percentage.		Water Evaporated from 32° to 212° per lb. coal.		Av. pure coal	Coefficient
	W'ter	Ash	Merch.	Pure		
1st—*Dry, with long flame.*					7.3x1146.6—8370	$\frac{8370}{14790}$—.57
Gerhardt Mine (Saarbruck)	5.10	6.84	6.85	7.78		
Leopold (Upper Silesia)	4.10	5.1	6.1	6.72		
Louisenthal (Saarbruck)	3.57	12.29	6.06	7.29		
Montceau (Saone and Loire)	4.97	10.28	6.2	7.41		
2d—*Oily, with long flame.*					8 lbs.9172	$\frac{9172}{15480}$—.6
Friedrichsthal (Saarbruck)	1.	12.7	6.31	7.78		
Attenwald	2.54	18.5	6.95	8.27		
3d—*Merchant.*					8.8 lbs.9090	$\frac{9090}{16200}$—.68
Ronchamp	1.09	16.19	7.62	9.16		
Le President (Saarbruck)	1.4	2.28	8.11	8.47		

Coal containing the carburets of hydrogen burns spontaneously when it is in large pieces, especially if it is at all damp or pyritous; and it is necessary in this case to keep the currents of air from the mass. If they are too pyritous in nature, they may be preserved or kept in basins full of water. Coals that are used in making gas change rapidly in the air; their loss in gas reaches about 30 per cent a month when exposed to the air. In practice the ashes reach a proportion greater than that which is given by chemical analysis; it reaches six to ten per cent for moderate size pieces, and varies from ten to twenty in current practice as coals run, and according to the care which the fireman takes in using them, and their nature. Coals are classified as large, intermediate, and fine coal; as they run it is a mixture of these three classes.

Briquettes.—Fine pieces of oily coal are agglomerated by heat; or small, oily or dry pieces are agglomerated with tar and clay. The calorific power of this material when thus dried, is deduced from that of the coal of which it is composed, taking it for granted that the matter is pure, and modified, of course, by the amount of water and ashes which it contains.

Coke.—This is the result of the distillation of the coal; it contains from 4 to 15 per cent. of ashes, or more, according as it it made from large or fine pieces, and according to the amount which is contained in the coal from which it is produced. It contains also from 2 to 10 per cent. of water. This fine coal, if it has been previously washed, gives a pure coke, and at a price higher than that which is made from the same grade of coal, but which has not been washed. Table A gives the average nature of coke for different coals. A cubic foot weighs from 43 to 48 lbs., and the gas about 15 lbs. The calorific power of the coke has not yet been exactly determined, but it may be deduced from the carbon which it contains by this formula:

$$P = 14{,}580\ (1-a-b).$$

According to the analysis of M. de Marsilly, dry coke contains on the average 4 per cent. hydrogen and 6 per cent. of ashes. For a coke containing 2 per cent of water and 10 per cent of ashes the proportion of hy rogen is reduced to .035.

$$P' = 14{,}580 \times 0.088 - 1009\ (0.02 + 9 \times .035) = 12{,}512.$$

ANTHRACITE.

This is the most brilliant of the coals; does not soil the fingers, and burns only at a high temperature. In America, and in Galle, where it is abundant and of good quality, it is employed in blast furnaces and for heating boilers. The anthracite coals of France are not very abundant, they crackle in the fire, and are useless for the purposes to which they are put in other countries. They contain on the average about 4 per cent. of water and 4 per cent. of ash.

The calorific power of the pure fuel is from 14,760 to 15,840. A cubic foot weighs 112 lbs.

TABLE C.

Nature of the fuel.	Wtr. pr ct	Ash pr ct	Calorific Power		Vol of gas	Vol at 572°	Weight of steam at 90 lb. from practi'e
			P	P'			
Wood, dried to 252°		2		7290	10.	21.	8.75
Ordinary wood	30	2		4770	8.3	17.4	2.5
Ordinary tanbark	48	12		2538	7.15	15.	.9
Peat	25	8	9135	5454	8.8	18.5	2.8
Lignite (perfect)	8	10	12780	11110.8	11.0	23.	5.12
Coal.							
Dry, with long flame	4	8	14850	12600	14	29 4	6.5
Oily, with long flame	2	10	15570	13320	16	34	3.85
Merchant	2	10	16290	13860			7.1
Oily (short flame)	2	10	17010	14508			7.34
Anthracitous $h = .4$	2	10	16470	14040	16.6	35	7.2
Anthracite	2	4	17532	15966	17.6	37	7.3
Wood charcoal	6	4	12600	12600	16	33.6	6.
Coke (good quality)				12438	17	36.	6.4

The tables (C) give a resume of the theoretical calorific power P of pure fuels, and of the actual calorific power of the fuel P′, the deduction having been made from the latent heat of the water evaporated. In making an application of the average co-efficient 6—10 (excepting in cases of tanbark, where the co-efficient is only 4—10) we obtain for the production of steam under the pressure of 90 lbs. to the square inch, about 1,179 calorics, which are taken from the figures given in the last column. For oily coal with a long flame we have

$$\frac{13{,}320 \times 0.6}{1{,}179} = 6.86 \text{ lbs.}$$

These weights of water evaporated, to which we will return, are those which we accept in the ordinary usage from a boiler that is well built and set up, with an external firebox.

LIQUID FUELS.

These fuels comprise petroleum and coal oils. They are rarely employed in the production of steam under ordinary circumstances, but we will give their calorific power from the scientific standpoint, as determined by M. Sainte-Claire Deville.

	Density.	Calo.Power.
Virginia and Pa. oils	.81 to .88	18,360
Heavy oils (Paris gas)	1.044	16,020
Oils from the schists of Autun and Pins	1.044	18,144

GASEOUS FUELS.

In foundries and blast furnaces the solid fuels are transformed into gaseous fuels under the influence of the air. In other cases these gases are obtained at the same time as the liquid fuels; that is, by the distillation of the fuel in closed vessels as in the case of illuminating gases. These gases are afterwards burned with a current of air in furnaces that are especially designed for them.

This mode of heating is only applied to the production of steam in the metallurgical works, as blast furnaces, etc. If it offers a better utilization of heat, it can only be used for continuous and regular work; it is therefore very inconvenient compared with the use of fuel upon grates, which allows the fire to be quickly banked in the evening, and to be started again in the morning. It is then only from a purely scientific standpoint that we give the calorific power of these gases.

Gas from a Lundin oven from wood sawdust containing 50 per cent. of water (Rinmann), 1823, calorific power; gas from peat having 18 per cent. water (Ebelmen), 1292: Siemens furnace from .75 oily coal, (Kraus), 1818; (Siemens) .25 dry coal, (Kraus), 1818;

blast furnace with wood charcoal, (Ebelmen—Bunsen), 1377; blast furnaces with coke, 1240; blast furnaces with crude oil, 2115; illuminating gas, water condensed, 20,322; illuminating gas density at 32 deg. =.52, water not condensed, 18,486.

VOLUME OF AIR NECESSARY FOR COMBUSTION.

Chemistry teaches us that one cubic foot of air contains 79 per cent of nitrogen and 21 per cent of oxygen. The density of oxygen is 1.43, and that of air is 1.293 at 32° Fahr., and under a pressure of 10 lbs. per sq. inch. Therefore

1 lb. of oxygen requires $\frac{1}{.92 \times 1.43} = 3.33$ lbs. of air.

Carbonic acid containing 72.73 parts of oxygen and 27.27 parts of carbon requires

$$\frac{72.73}{27.27} = 2.667 \text{ lbs. of oxygen}$$

or $2.667 \times 3.33 = 8.88$ lbs. of air at 32° Fahr.

Water being composed of 88.9 parts of oxygen and 11.1 of hydrogen shows that t burn one pound of hydrogen requires

$$\frac{88.9}{11.1} = 8 \text{ lbs. of oxygen}$$

or $8 \times 3.33 = 26.64$ lbs. of air at 32° Fahr

Knowing the quantity of carbon (C) and of free hydrogen (H) contained in one pound of the fuel, we can deduce the amount of air (V) necessary for its combustion.

We have $V = C \times 88.8 + 26.64\left(H - \frac{O}{8}\right)$

Example. For one pound of wood having 30 per cent of water and containing:

Carbon	0.35
Hydrogen	0.042
Oxygen and nitrogen	0.294
Water	0.3
Ashes	0.014

the free hydrogen is $0.042 - \frac{0.294}{8} = 0.005$.

(This $\frac{0.294}{8}$ is taken because a portion of the hydrogen goes to unite with the oxygen and therefore lessens the amount of air required by the hydrogen available for combustion. *Trans.*)

The volume of air required to burn this pound of wood will be $0.35 \times 8.88 + .005 \times 26.64 = 3.24$ lbs. of air.

For a dry coal containing 12 per cent of ashes and water or 0.88 of the pure fuel, we deduce from table (A) the average composition:

$$\left.\begin{array}{lll}\text{Carbon} & 0.775\times 0.88 & =0.682\\ \text{Hydrogen} & 0.05\ \ \times 0.88 & =0.044\\ \text{Oxygen} & 0.175\times 0.88 & =0.154\\ \text{Water and ashes} & & \ \ .12\end{array}\right\}1\,000$$

The free hydrogen will therefore be

$$0.044-\frac{0.154}{8}=0.025$$

and the volume of air

$$0.682\times 8.88+0.025\times 26.64=6.72\text{ lbs.}$$

In practice the volume of air required is from two to three times as great as that which we have specified; first, because the combustion is not perfect; second, because of the necessity of frequently opening the fire-box door.

According to Messrs. Scheurer-Kestner and Meunier, the maximum result from a fuel burned under steam boiler, is obtained when the excess of air reaches about thirty-three per cent. After combustion the voume of the gas is the same as that of the air, since the carbonic acid has the same volume as the oxygen which formed it, but it is increased by the volume of steam formed by the water resulting from the combustion of the hydrogen. The volume of this steam or vapor is about six per cent. for wood and peat in a dry condition, and about eight per cent. for the same, damp, and four per cent. for coal.

Table (C) contains the volumes of this gas (V) which is double the theoretical volume plus that of the vapor. Thus for the dry coal we have

$$V = 2 \times 6.72 + 0.4 = 13.84 \text{ lbs.}$$

The volume of air in the table (C) is applied to furnaces having a free draft, and it is generally admitted that in case when the draft is forced either by an injector, ventilator or by a steam blower in the smoke stack, the volume of air that will be necessary (W) is from 6 to 7% of V, as we have already specified. Finally the total volume of gas V expanded to the temperature t of the chimney will give the volume V which ought to pass thus:

$$V' = V\,(1 + 0.00367\,t)$$
$$\text{for } t = 300^\circ \text{ is } V = V \times 1.55$$
$$\text{for } t = 570^\circ \text{ is } V = V \times 2.1$$

COMBUSTION AND FIREBOXES.

We have seen that the carbon and hydrogen are the elements of combustion by means of which heat is obtained. Carbon is fixed (coke, and wood charcoal) or contained in the volatile hydrocarbons. Coke and wood charcoal constitute the solid fuels that burn only upon the surface and are therefore luminous. The fuels containing the hydrocarbons are decomposed by heat and the combustible gases which are set free produce a flame which is only luminous upon that portion of its surface which is in contact with the air.

In dividing the fuels and the flame, we increased the surface of contact with air, so that the combustion is more rapid and more complete. The heat produced by the combustion of a body is dissipated; first, by the current which is generated about the body, and second, by radiation.

This power of radiation when considered in proportion to the total calorific power, is according to Peclet about twenty-five per cent for fuels that are burning with a flame and fifty per cent for glowing coals.

The following table gives the weight of oxygen and air necessary to burn 1 lb. of hydrogen or 1 lb. of carbon according as the latter is transformed into carbonic oxide (CO) or into carbonic acid (CO^2), also the amount of heat set free, in which case reference is made to the first part of this section.

1 lb. of fuel.	Theoretical Oxygen.	Requirements. Air.	Heat Produced
Hydrogen....	8 lbs.	26.64 lbs.	62,028.
Carbon transf'med into $\{CO$..	1.333	4.44	4,451.4
CO_2	2.666	8.88	14,580.
Difference...			10,128.6 heat units.

At the commencement of combustion 1 lb. of carbon (C) unites with 2.666 lbs. of oxygen and forms 3.666 lbs. of carbonic acid (CO^2), setting free 14,580 heat units. The volume of carbonic acid is the same as that of the air from which it was formed, but its density is greater; the combustion is then complete, but if the air is wanting in quantity, the 3.666 lbs. of carbonic acid (CO^2) absorbs 1 lb. of carbon, forming 4,666 lbs. of carbonic oxide (CO). The heat set free by these 2 lbs. of carbon and transformed into carbonic acid is

$$2 \times 4451.4 = 8902.8.$$

The loss resulting from the absorption of these 2 lbs. of carbon is then

$$14,580 - 8902.8 = 5677.2 \text{ heat units.}$$

If now we furnish these 4.666 lbs. of carbonic oxide (CO) the oxygen which is necessary to complete this combustion, or

2.666 lbs., it will burn with a blue flame, and we shall have 7.333 carbonic acid (CO^2); the heat set free will be

$$2 \times 10.128.6 = 20,257.2,$$

which added to the heat (CO) 8902.8 gives exactly 2 × 14,580=29,160 heat units. That is to say, the heat resulting from the complete combustion of 2 lbs. of carbon.

COMBUSTION OF THE HYDROCARBONS.

These gases, mixed with a sufficient quantity of air, burn with a blue flame, producing carbonic acid (CO^2) and water like illuminating gas. For instance, if they are raised to a high temperature before they are mixed with air sufficient to effect their combustion, they are decomposed in their turn; the hydrogen burns first, and a part of the carbon is set free; this carbon then burns in its turn if it is in the presence of oxygen, and if the temperature of the mixture is sufficiently high. On the other hand, the combustion is incomplete and the carbon is set free, being held in suspension in the gas where it forms smoke, which, if it is cooled, is deposited in the shape of soot.

SMOKE ONCE FORMED, CANNOT BE BURNED.

It is necessary then in order to avoid its production, to mix in the combustible gases a sufficient quantity of air at a high temperature in order that the combustion may be complete. This rule, simple as it is, has not yet been realized in practice, at least in the case of ordinary furnaces. In the gas works, to be sure, they have a kind of smoke consumer, but, as we have already stated, an apparatus like this is not usually adaptable to the regular and continuous use of ordinary practice.

It will be seen in a future number that the fire-box as arranged by Tenbrink, has given good results.

(For a description and cuts of this boiler, we refer the reader to the forthcoming matter on steam boilers by the same author. *Trans.*)

MANIPULATION OF THE FIRE.

We will only speak of the coal as the fuel in this connection.

We know that the gases resulting from combustion and the affluent air ought to be raised to, and maintained at a very high temperature, in order to obtain complete combustion. The turning back of the flames upon the bed or brickwork produces this mixture of gases, and gives us a combustion which is preferable to that which takes place when the gases rise vertically from the grate. This combustion should be completed in an open space or chamber called the combustion chamber, which may be a portion of the furnace space or connected with it. It is necessary then to avoid having the flames impinge directly upon the tubes where they are cooled, holding them there before their combustion is completed, depositing a large amount of soot and giving out more smoke. Often these combustible gases thus drawn through the tubes, burst into flame when entering the chimney.

There has been a strenuous endeaver to raise these gases and suppress the smoke by the injection of steam or air, which is sometimes let in at the sides of the fire box, sometimes over the bed or by means of the door, in a continuous or in an intermittent way. We will not describe all of these advantages, partaking more or less of the character of smoke consumers, none of which have up to the present time been permanently successful.

An excess of air is preferable, for the loss of heat which results is less than that which results from incomplete combustion. A smoke burner needs an excess of air but it is not necessarily economical. The combustion would not be perfect and it will always have more or less smoke.

Skilful firemen could obtain the same economy as the best furnaces. The conclusions upon this subject are taken from Instructions Upon the Means of Preventing Smoke, drawn up by the Hygienic Council of the Seine, and from which we make the following quotations:

"The origin of smoke lies in the volatile products which are rapidly set free from most fuels; such as the different varieties of coal, peat, and wood when they are constantly exposed to an elevated temperature. These products are for the most part hydrocarbous which are themselves highly inflammable, and in order that they may burn two conditions are necessary. First, they must be mixed with the proper amount of air. Second, these mixtures must be raised to a high temperature. If these two conditions are not realized in the fire-box itself, or in the flues through which the gaseous products are led, the hydrocarbon undergoes a decomposition which results in abundant deposit of soot or carbon in finely attenuated particles which are drawn by the current of gas through the orifices to the chimney. When we throw upon a grate which is not really covered with incandescent coke, a considerable quantity of coal so that it is covered to a total depth from eight to nine inches in thickness, the fresh particles of coal which find themselves in contact with the coke, undergo a rapid distillation; the temperature in the fire-box is suddenly lowered, at the same time the passage of air through the grates and the bed of fuels is obstructed. Neither of the two conditions necessary for the burning of the carborate of hydrogen are realized, thus we see torrents of black smoke coming out of the chimney. The introduction of air in such circumstances by way of the furnace door or by any other means opening directly over the coal, is without effect, because the temperature is insufficient to inflame the gaseous products. The smoke gradually decreases, and does so in proportion as the coal is converted into coke or the decomposed into the volatile parts, and as the air gains freer access through the fuel which has agglomerated into lumps, allowing larger intervals between the pieces, and as the temperature is again raised by the effects of the combustion. If before the distillation is completed, we stir up the mixture of coal and coke that is lying upon the grate, with a poker, we put portions of the coal which are not yet carbonized, in contact with fragments of coke that are very hot. The distillation then becomes very rapid and is accompanied by the reappearance of smoke.

"Furnaces whose grates are somewhat extended, so that the charges of fuel only cover them in part, and where the bed can be kept thin, give out very little smoke, especially if the coal is fired in small quantities at a time and if the fireman takes the precaution to throw the coal on the front portion of the grate so that the gaseous products of distillation reach the flues in passing over the heated surface, which covers the back portion of the grate and thus allows a sufficient amount of air to pass up through it. The production of smoke is considerably increased by having the grates of too small dimensions in proportion to the quantity of fuel, which is burned upon them in a given time, and by a bad manipulation of the furnace on the part of the firemen, who do their work at too great intervals of time, or use too much fuel at one firing. It has also further increased, other influences being equal, when fuels containing large proportions of volatile gases are used, or to speak only of those which are the most oily and have the greatest tendency to coke, the dry coals of a few departments of the North in the neighborhood of Charleroi in Belgium give out only a little smoke in furnaces which are tolerably well constructed and have ordinary care and attendance. The coke gives none at all, but escapes through the chimneys of those furnaces which are fed with this fuel, as a colorless gas, taking a small quantity of ashes in an extremely attenuated condition. Coal containing little hydrocarbon gives very little smoke and offers a great advantage in not burning spontaneously when it is banked up in large quantities."

When a piece of coal, the size of a man's fist, is thrown into the fire-box, it brightens slowly in burning; the center remains unchanged up to the time when its combustion takes place. Care must be taken that the fire is only raked over at infrequent intervals, since the coal does not burn easily when the mass is being continually broken up and drawn across the grate.

The depth of coal upon the grate ought to be uniform and in proportion to the draft, and not less than four inches or more than six inches in depth. The fireman should arrange this matter by the flame, which should be white when the combustion is good. A red flame indicates an incomplete combustion because of too great thickness of the fuel bed. A fire should be replenished by throwing the coal upon those parts which are burning most brilliantly. The large pieces ought to be broken up with a pick in the line of their cleavage in order that the pieces should not be crumbled; that is, small pieces should be thrown in a thin and uniform layer over the furnace when it is in full blast, and the fireman should avoid putting a too heavy bed upon the same places or where the fire is not burning brightly. When a plant has large grates, it is preferable to replenish the fire alternately upon each half of the grate. The combustion which will thus be obtained is far better than firing over the whole surface at once.

TESTS OF EVAPORATION.

The economic value of a plant as a whole, that is, the boiler and engine, results not only from the good utilization of the steam in the engine, but also from the evaporative power of the boiler. If, at the same time that the indicated or effective work is noted, the amount of water fed to the boiler is also measured as well as the weight of the fuel that is burned, we will have a real basis for estimating the value of the plan, by the water and fuel consumed. We will thus have the evaporative power of the boiler, that is, the quality of the steam produced per pound of fuel.

The greatest evaporation per pound of fuel depends upon the quality of your fuel, the good proportions of the furnace and boiler, the condition under which they are kept, and last of all but by no means least, upon the ability of the fireman. Thus the results of evaporative tests cannot be compared with each other when they are made in the same fire box with different qualities of fuel or with the same fuel in different furnaces, even although they may be made in both cases by the same fireman. When tests are made for the reception of the plant and the nature of the fuel is specified, the builder determines the figures which he can guarantee, from the calorific power of the fuel itself, and arranges his furnaces to obtain the best combustion for it. On the other hand, when no fuel specification is made, he will employ that fuel which will produce the highest rate of evaporation.

From the commercial point of view of the production of steam, the best combustion is that which will produce per pound of fuel the highest rate of evaporation at the same price. We will suppose that two kinds of coal are to be tried in the same fire box and under the same conditions. One ton of coal costing $4, will evaporate say 13,000 lbs. of water, or

$$\frac{13,000}{4} = 3,250 \text{ lbs. of steam per \$1.}$$

One ton of the other, costing $3.20, will evaporate 10,000 lbs. of water, or

$$\frac{10,000}{3.2} = 3,125 \text{ lbs. of steam per \$1.}$$

With these figures the dearest coal therefore is the most economical. If we are driving an engine of 100 H. P. consuming 20 lbs. of steam per H. P. per hour and working 300 days at ten hours each during the year, the expense will be, with the $4 coal,

$$\frac{300 \times 10 \times 100 \times 20}{3,250} = \$1.846.15$$

With the coal at $3.20

$$\frac{300 \times 10 \times 100 \times 20}{3125} = \$1,920.$$

The annual saving will therefore be $73.85. Furthermore we will have 92.3

tons less to store, or at the rate of 7.7 tons per month. We can readily see, then, what importance these calculations assume when large industries are taken into consideration.

Tests of this kind have been made by M. P. Ducos, an engineer at Bordeaux, with English coal in regular usage, having a boiler with 1,063 square feet of heating surface and 32 square feet of grate. The pressure of the steam was taken at five atmospheres absolute, or at an effective pressure of 59 lbs., with feed water estimated on a basis of 32° F. The hydrometric conditions and the amount of ashes were determined in advance, but are not indicated by M. Ducos.

Kind of coal.	Price.			Evaporation per lb. of coal.
	Per ton ready for use.	Per 20 lbs. of steam.	Compared with Cardiff.	
Cardiff........	3.0	3.838	3.0	7.816
Liverpool.....	2.6	4.876	2.36	5.832
Newcastle....	2.9	5.261	2.2	5.507
Coke with 6 per cent of water.......	2.8	5.259	2.2	5.324

TESTS OF EVAPORATION.

The Cardiff coal, although costing the

most, was therefore, in the case just cited, the most economical.

The firm of Decker & Co., of Cannstatt, (Wurtemburg), has obtained the following results under a battery of boilers with Tenbrink furnaces.

Kind of coal.	Per cent of ashes.	Coal per lb. of water evaporated.	Cost of coal per ton (2240 lbs.)	Cost per 100 lbs. water evaporated.	Evaporation per lb. coal.	Coal burned per sq. ft. grate surface.
Herne Bochum,	12.5	.1018	$4.87	.022	9.82	6.73
Heinitz, 1st quality	7.5	.1006	4.76	.021	9.93	6.70
Izenplitz, 2d "	12.5	.1115	3.82	.019	8.97	7.00
Reden, 2d "	10.2	.109	3.99	.019	9.17	7.07
Konig, 3d "	19.5	.1332	3.10	.018	7.51	8.29

CONDUCTION OF THE TEST.

A test ought to be as prolonged as possible and to be made in the regular working of the plant, that is to say, some time after the fire has been started, in order that the loss of heat which occurs through the heating of the mason work should be that of regular practice. The test can be made without deranging the regular working conditions.

At the beginning of each operation the grates and fire should be carefully cleaned and then an estimate made of the coal which is upon the grates; and it should be so arranged that there should be the same quantity left at the end of the test.

In general the total expense of the fuel is that which is burned during the test, plus that which remains upon the grate at the end, reduction having been made of that which was upon the grate at the beginning and of the coked portions which can be used from among the cinders.

The gauging of the water may be made first, by taking the dimensions and number of strokes of the supplying feed-pump; second, by a water meter; third, by automatic feeders which are also meters; and finally, by tilting gauges; this last alone should be employed for rigorous tests.

Care should be taken, as far as possible, that, at the end of the test, the water in the boiler should have the same level and the same steam pressure should exist as at the beginning. When this is not the case a correction should be made.

Correction:—It is necessary to ascertain accurately the level of the water in the boiler at the beginning and the end, for indications of the gauge-glass are not exact. In fact, the water has a lower temperature in the glass than in the boiler. It is therefore more dense and its level is lower than in the latter.

If we open the cock at the bottom of the tube for a moment, the water which refills the tube will then have the same temperature and be at the same level as that of the boiler. It is necessary that this should be noted instantly, for the water is soon cooled and its level lowered. The difference in the levels *h'* Fig. 1, increases with the difference in temperature between *h* and *h'*; and also with the length of the glass or of the level of *h'* above the lower connection, which is an important matter when the lower tube is screwed far down in the boiler.

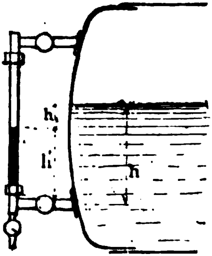


FIG. 1.

If we take it for granted that the temperature of the water in a tube stands at 104 degrees, its co-efficient of expansion will be

.000259, and we obtain the following values for h^2 in inches, for the different temperatures per inch of height of water taken at the temperature of 32 degrees Fahr.; $h' = h - h' = .000259\ (t-104)$.

Absolute No. of atmospheres.	1	2	4	6	8	10
Temperature t.	212	248	291	319	338	356
H° per in. of water at 32°	.028	.037	.048	.055	.06	.065
Volume of water at 32°	.973	.964	.954	.947	.943	.938

Suppose then we have observed the exact level and the pressure before and after the test; the tables of Regnault which are appended give the corresponding temperatures.

(These tables will appear in a future number of this work.—*Trans.*)

The correction consists of collecting the number of calorics contained in the boiler before and after the test.

We calculate first the volume V, reduced to a temperature of 32 degrees. For a cubic foot which appears in the boiler at the temperature t, we have the formula:—

$$V = \frac{1}{1 + 0.000259}\ (t - 32)$$

(This 32 is the constant number to bring the temperature as read upon a Fahrenheit thermometer to the number of degrees above freezing. With the centigrade thermometer no such reduction is necessary. *Trans.*)

The volumes are then indicated in the above table.

We then calculate the number of contained calorics: 1st, in the weight of water thus corrected; 2nd, the calorics in the metal, by taking the calorific capacity of the iron, for temperatures ranging from 32° Fahr. to 400° Fahr. as equal to .115 (Duong and Petit.)

We can then neglect the variation of heat contained in the steam itself as resulting from the effects of expansion.

Knowing the number of calorics gained or lost by the boiler, we deduct the equivalent weight of fuel according to the mean amount of heat that has been utilized, at from 7,000 to 9,000 heat units per pound of coal. For example: In a boiler of 48 inches diameter and 50 feet long, we have ascertained after the trial that the water has lowered in its level four-tenths of an inch, and that the pressure has fallen from four to six atmospheres. The feed water being taken at 59°. From the size of this boiler we have

	Apparent Volume.	Pressure.	Temperature t.	t—59
Before the test.	4728 gal.	6 at.	319	247
After " "	4253 "	4 at.	291	219

The corrected volume at 32° Fahr. and the amount of heat will be:

Before: 4728 × .947 = 4477.416 gals. as the volume at 32° Fahr. Multiply by 8.33 as the weight of one gallon of water, we have 4477.416 × 8.33 = 37,296.975 lbs.; multiplying again by 247,

37,296.975 × 247 = 9,212,352.5 heat units.

Then after the test, following the same rule,

4253 × .954 = 4057.362 which × 8.33 = 33,797.825, and this × 219 = 7,401,723.7.

Then having 9,212,352.5, subtract 7,401,723.7, leaving 1.810,628.8 heat units.

The boiler weighing 33,000 lbs. has lost 33,000 × .115 (319—291) = 106,260 heat units.

The total loss of heat is equal to

1,810,628.8
106,260

1,916,888.8 heat units,

which represents at least

$$\frac{1,916,888.8}{7000} = 273.84 \text{ lbs. of coal.}$$

	Water in lbs.	Coal in lbs.
Consumed during the test	15,840	2,750.
Consumed after rectification	3,499	273.84
Actual consumption	19,339	3,023.84

(The 3,499 lbs. is the difference in the weight of water before and after the test.)

The real evaporative efficiency per pound of coal is then

$$\frac{19,339}{3023.84} = 6.4 \text{ lbs. of water.}$$

If the level of the water had been raised instead of lowered, the loss after rectification would have been taken from those that had been indicated during the test. A test made during the regular working of the plant will give an evaporative figure somewhat exaggerated, if the engine causes the boiler to prime, as frequently happens. There is no particular method of ascertaining the amount of water drawn off under these circumstances. It is shown in another portion of the work that the calorimetric system can be applied to this case. (This test will appear in another volume of this work. *Trans.*)

Dry steam is colorless, and if we open a cock, the jet of steam will be invisible as it comes out, until it contains more than three to four per cent of water. As the jet leaves the cock, it assumes a cloudy appearance in consequence of the condensation of the steam. If, on the other hand, the steam contains a large percentage of water, it presents this cloudy appearance from the very start. When the tests are made while the plant is out of use, priming can be avoided by proceeding as follows: We run the engine very slowly under a light load, but rapidly enough and with sufficient regularity to require a regular supply of steam from the boiler, yet having it as light as possible. The surplus of steam furnished by the boiler is lost in the atmosphere by means of the safety-valves. The water and fuel are measured as we have already indicated.

We have not spoken of the fuel that is burned while we are getting up steam. Its importance diminishes as the duration of the test is lengthened out. Nevertheless, it is necessary to take an account of it, if we compare the boilers of different systems;

for instance a boiler holding a large volume of water, with one holding a small volume. The first will require upon the first day a considerable quantity of fuel in order to get up the pressure; but afterwards it will require very little on account of the heat which is stored up in its mass. The second apparatus, on the other hand, will require almost the same quantity each day. The comparison will only be correct then, if we take into account the whole amount of fuel that has been burned upon each day, and during the whole progress of the test.

We have said that we can measure the water fed into the boiler by means of a meter. This meter can serve to control the manipulations of the boiler, just as a totalizing indicator controls the manipulations of the engine. In fact, in comparing the indications of the meter with those of the totalizer, and also with the fuel which is burned each day, we can make a correct statement of the amount of evaporation which has been performed, and of the importance which should be attached to priming, and also the amount of incrustation, if we continue our tests for a long enough time. This will be the best method of ascertaining the skill of the firemen.

THE CONTROL OF COMBUSTION.

The Orsat Apparatus.—Perfect combustion only takes place in the furnace and flues when the carbonic acid gas that has

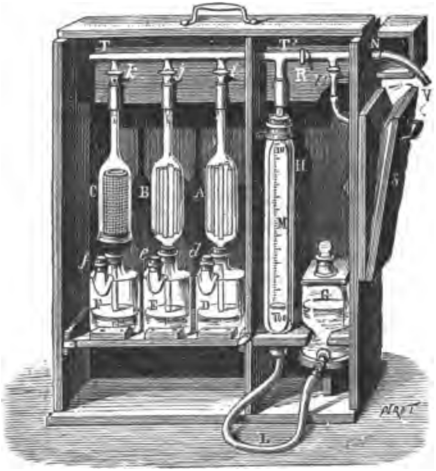


FIG 2

been formed has the same volume as the air which furnished the oxygen, plus that of the nitrogen. But, in reality, there is always a certain amount of carbonic oxide, whose volume is twice that of the air formed, plus the oxygen taken from the air and not burned.

The Orsat apparatus is only another and modified form of the endiometer of Regnault and Schloesing, which has been so perfected by its maker, Salleron, that it permits those three gases, oxygen, carbonic oxide and carbonic acid, to be rapidly measured, and to deduce therefrom the amount of each (O, CO and CO^3) by eliminating the amount of nitrogen; and consequently to learn what volume of air corresponds to one cubic foot of the gaseous mixture.

The apparatus is composed first of an aspirator of the gas (Fig. 2), *G* and *M*, serving to measure its volume at the beginning of the experiment, and after its absorption by each reacting agent; second, a series of three retorts (*A*, *B*, *C*,) in which the absorption of each gas is successively effected by means of a suitable re-agent; third, a bellows *S* which has for its object the clearing of the conduit that puts the apparatus in communication with the reservoir of the gas that is to be analyzed.

G is a flask containing acidulated water; acidulated by hydro-chloric acid, which takes away from it the property of dissolving carbonic gas. This flask communicates by means of a rubber tube *L* with the lower part of the graduated tube *M*, which is called the measurer, and is itself enclosed in a glass casing filled with water in order that the measurements may all be taken at the same temperature. The upper end of the measure is connected with the horizontal tube *T T*, which is made of glass having the valve *R*, as well as the three vertical tubes which are furnished with the cocks *i*, *j*, *k*. These small tubes are connected in turn by means of rubber tubes attached to the upper extremities of the glass necks of the retorts *A*, *B*, *C*; while the lower necks are run down into a liquid contained in the flasks *D*, *E*, *F*. The joints of the different connections of the apparatus are hermetically sealed by means of wax and a fine brass wire. The openings, *d*, *e*, *f*, of the flasks are closed by rubber stoppers.

The apparatus is put into connection with the reservoir containing the gas to be analyzed by means of the rubber tube *V* which is attached to the end of the glass tube *T*. Finally a bellows *S* is attached to the outside of the casing and communicates with the glass tube through the cock *r*, thus permitting it to extract the air from the conduit *V*.

In order to make the tests which we are to undertake, it is necessary to know the proportions of carbonic acid, carbonic oxide and oxygen which are contained in the gas. The re-agents are first, soda lye as absorbent of carbonic acid; second, a solution of pyro-gallate of potash as the absorbent of the oxygen; and third, an ammoniacal solution of the proto-chloride of copper to separate the carbonic oxide. The retorts *A* and *B* contain a large number of glass tubes which are wet with the solution in order to multiply the amount of surface which the re-agents can bring in contact with the gas, and thus hasten the absorption.

C contains a quantity of red copper foil which, by being dissolved in the hydrochlorate of ammonia, produces the protochloride of copper, and the production of the re-agent. The pyrogallate of potash and the ammoniacal chloride of copper being absorbents of oxygen, it is necessary that care should be taken that the contents of the flasks *E* and *F* do not come in contact with the air. For this purpose we cover the liquid with a film of petroleum oil about a twentieth of an inch in thickness. But it is necessary to take care in the manipulation that it does not pass into the retorts where the absorption takes place.

We now proceed to methods of the analysis itself. The cock *R* is opened in such a way as to put the apparatus in communication with the atmosphere. An aspirator *E* is raised up; the acidulated water then runs down and fills the measurer completely, driving out the air which formerly was contained therein. We then close the cocks *i* and *j* and open the cock *k*, and take out the stopper *f*. In letting down the flask *G* we produce an inhalation of the air contained in the retort *C*, which is then filled with the liquid which was contained in the flask *F*. We raise the level of the liquid up to the mark which is cut upon the tube that runs from the top of the retort, then close the cock *k*. We then open the cock *R*, and raising the aspirator, we fill the measurer with water once again; then closing *R*, we open *j*, take out the stopper *e* and draw up into the retort *B* the liquid contained in the flask *E*. Repeating this same movement a third time, we cause the liquid that is contained in the flask *D* to flow up into the retort *A*. We now open the cock *R* again, and then raise the aspirator in such a manner as to fill the measurer up to the upper mark indicating the zero point of the graduation. We close the cock *R* and then establish by means of the tube *N*, as shown in the engraving, the communication of the apparatus containing the gas that is to be analyzed. We open the cock *r* and operate the bellows, blowing into the tube *V* until it is freed from the air and gas which is left from the preceding operation. After a few moments, when we are certain that the conduit *V* is entirely filled with the gas which we are to analyze, then close the cock *r* and open the cock *R*, in such a way as to put the tubes *T* and *V* into communication, and to isolate the bellows. The water flows into the aspirator until the measuring tube is full of gas, and when it is at the same level in both, we close the cock *R* so as to separate the apparatus from the conduit and the bellows. Then, we examine to see that the gas, which we are going to analyze, occupies just one hundredth part of the graduated tube M. We open the cock *i* and close the flask *G*; the water drives the gas into the retort *A* which contains the soda lye, the nest of glass tubes multiplying the surfaces of contact, and the carbonic acid is absorbed; we lower the aspirator and the gas again fills the measurer, and the retort *A* is filled with the lye; we force it up until it reaches the mark put upon the glass, and then close the cock *i*. We place the flask *G* in such a manner that the water which it contains will be upon the same level as that of the measurer, in order that the gas which is there contained may be subjected to atmospheric pressure alone. We then read the volume occupied and the difference between the reading made before the absorption, and that which is made afterwards, gives the volume of carbonic acid gas which has been retained by the soda.

We open the cock *j*, and, operating in precisely the same manner with the retort *B*, which contains the solution of pyro-gallate of potash, we ascertain the volume of oxygen absorbed. Finally we repeat the same manipulation with the retort *C*, which was filled with a solution of the ammoniacal proto-chloride of copper, and obtain in the same manner the volume of carbonic oxide.

If, after these three absorptions, any gas remains, its volume represents the nitrogen which can not be absorbed by any of the re-agents which we have been using. In order that the absorption may be complete, it is absolutely necessary to wash the gas several times in each retort. We do not proceed from one washing to another until two consecutive readings are identical.

The absorption of the carbonic acid is more rapid as the concentration of the lye is greater. It is necessary then to replenish the liquid in the flask, and when the reaction becomes too slow, that is to say, when the greater part of the alkali has been transformed into a carbonate. The solution of the potash has the same concentration as that of the soda. It is best to add the pyro-gallate acid just at the time when the experiment is to be made, and in proportion to the quantity and volume of the oxygen which we anticipate it will be necessary to absorb.

The ammoniacal proto-chloride of copper is obtained by the dissolving of the copper foil in a liquid formed by two-thirds of a solution of hydro-chlorate of ammonia and one-third of ordinary ammonia at a temperature of 72 degrees.

The proto-chloride of copper has the property of absorbing oxygen also. In order that the last reaction indicated may exactly represent the carbonic acid, it is necessary then that no oxygen should remain unabsorbed by the pyro-gallate of potash. The production of the proto-chloride of copper is somewhat slow. It is sometimes advantageous to replace this product by proto-chloric acid, which also has the property of absorbing carbonic oxide. We find this in the form of a crystalized salt upon the market, but is partially altered by contact with the air. We therefore put it into the flask *F*, where we dissolve it in hydro-chloric acid, and in order to bring it into the proto-chloride state, we add a few pieces of copper turnings. The liquid, which is at first brown, becomes discolored. We keep it under a film of petroleum, as we have already indicated above.

If we are working with one hundred volumes of gas, and if

x = the volume of nitrogen,
y = the oxygen and carbonic acid gas,
z = the carbonic oxide,

we will have

$$x + y + z = 100;$$

$$\text{and } \frac{x}{y + \frac{z}{2}} = \frac{79}{21}$$

Replacing y by its value taken from the first equation, we have

$$100x = 7{,}900 - 79\frac{z}{2}$$

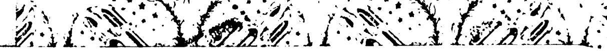
from which z may be obtained when x has been found by analysis.

(The End.)

ska
le met

89089673800

B89089673800A



b89089673800a